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Spatial and Temporal Variability of Nitrogen Deposition and Its Impacts on the Carbon Budget of China

Xuehe Lu[a], Hong JIANG[a,b*], Jinxun LIU[c], Guomo ZHOU[b], Qiuan ZHU[d], Changhui PENG[d], Xiaohua WEI[e], Jie CHANG[f], Shirong LIU[g], Shuguang LIU[c], Zhen Zhang[a], Ke WANG[a], Xiuying ZHANG[a], Allen SOLOMON[h]

[a] *International Institute for Earth System Science, Nanjing University, Hankou Road 22, Nanjing 210093, China*
[b] *State Key Laboratory of Subtropical Forest Science & Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon Sequestration, Zhejiang Agriculture and Forestry University, Hangzhou，311300, Zhejiang，China*
[c] *Stinger Ghaffarian Technologies (SGT, Inc.), contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, 47914 252nd St., Sioux Falls, SD 57198. Work performed under USGS contract 08HQCN0005.*
[d] *Institute of Environment Sciences, University of Quebec at Montreal, Montreal C3H 3P8, Canada*
[e] *Department of Earth and Environmental Sciences, University of British Columbia (Okanagan), 3333 University Way, Kelowna, BC, Canada V1V 1V7*
[f] *College of Life Sciences, Zhejiang University, Hangzhou 310058, China*
[g] *Institute of Forest Ecology and Environment, Chinese Academy of Forestry, Beijing 100091, China.*

Abstract

Nitrogen deposition in different regions has different volume and rate. And the impaction of nitrogen deposition is also inconformity on the different ecosystems. In order to study the atmospheric deposition of nitrogen stress on the carbon cycle, we analyzed the history, present and future trends in the evolution of nitrogen deposition, using remote sensing data and models. At the mean while, a series of spatial and temporal nitrogen deposition data was established and install into the Integrated Biosphere Simulator (IBIS), in order to found out the effects of different nitrogen deposition levels on the carbon budget in China. GOME and SCIAMICHY remote sensing data provide us a long time series of nitrogen dioxide column concentration data which can be fitted by the sine function. So it was used to construct nitrogen deposition data associated with ground observation data and recent research results of nitrogen deposition (dry and wet). Along with the nitrogen deposition data, two climate change seniors (A2 and B1) were used to drive the IBIS model. Comparing impact of different nitrogen deposition level, six simulation experiments have been set. The results show that ecosystem responses to nitrogen deposition will be different under future climate change scenarios. In the aggregate, more nitrogen input may not be able to bring more NPP and NEP in the future. At the meanwhile, the responses of different vegetation types to nitrogen deposition will show significant differences.

* Hong Jiang. Tel.: +86-025-83595969;
E-mail address: jianghong_china@hotmail.com.

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Nitrogen saturation will occur in some vegetation types. Further study, we will promote the accuracy of the nitrogen deposition simulation and try to make greater efforts on impaction of nitrogen deposition in global scale.

Keywords: nitrogen deposition; climate change; carbon budget; IBIS; model

1. Introduction

Nitrogen cycling has been alert by human beings than by any other nature processes combined [1-3]. In recent decades, nitrogen oxide exhausted from the fuel combustion and ammonia volatilized from the agricultural fertilization have increased the nitrogen concentration in the atmosphere. The reactive nitrogen produced in this process has increased from less than 1TgN/yr in 1860s to 25TgN/yr around 2000[4-5]. The nitrogen in the atmosphere deposits to the terrestrial ecosystem by the approach of dry deposition and wet deposition. With the increasing nitrogen concentration in atmosphere, the Global nitrogen deposition level will double in the next 25 years[6].

Nitrogen is a main factor which limits land vegetation photosynthesis[7], and it takes great effect on the ecosystem. The rapid increase of atmospheric nitrogen deposition greatly interfere ecosystem carbon cycling and carbon storage by its direct or indirect effect on vegetation growth, carbon fixation and allocation of photosynthate[8]. Nitrogen deposition plays an important role in adjustment of ecosystem and it also became the hot spot in ecological field.

The effects of nitrogen deposition are concerned by many researchers, but it still has great uncertainty. Nitrogen in the soil is not same in different ecosystems which assume to three states. They are nitrogen deficiency, nitrogen balance and nitrogen saturation[9]. How nitrogen deposition changes take effects on ecosystem carbon sequestration, coupling with different nitrogen conditions in the soil, is a complex issue. Some inconsistent views appear in the current studies. Much research has indicated that nitrogen limits the vegetation response to the elevated CO2[10-13].They also indicate that N deposition is predicted to have increased net primary productivity due to increases in foliage area and foliage N, contributing 0.1–2.3 Pg C yr^{-1} from the atmosphere [14-15; 3].Other research find that nitrogen deposition take a little effect on the carbon sequestration. They addressed only 0.25 Pg C yr-1 uptake resulting from nitrogen deposition[16].

In summary，How N deposition takes effect on ecosystem carbon budget is still an uncertainty issue. Fortunately, we have the remote sensing data which address us another way to explode the relationship between the nitrogen deposition and carbon sequestration. Long time continuous satellite observations provide us with spatial and temporal dynamic of nitrogen deposition. These global scale observations are another approach to analyze nitrogen cycling over large regions. However, the atmospheric nitrogen dioxide column density, got from the satellite, can't be applied to the study of ecological systems directly. In order to apply the remote sensing data to the study of ecological systems, we must translate the nitrogen dioxide column density into the surface concentration. Some studies show that column density and the surface concentration has significant correlation [17-18]. And the time series of nitrogen dioxide can be described well by sine function [19]. These previous studies provide us a new perspective to use the remote sensing data.

Remote sensing data associating with terrestrial ecosystem system model is a powerful method to research the carbon sequestration on the sensitivity of the nitrogen deposition. Many C-N models were developed in recent decades that focusing on various vegetation type, temporal and spatial scales mechanism. The Integrated Biosphere Simulator (IBIS) is a processed model that considers C nitrogen and water cycles and it has been applied in many regions around the world[20-21].

Carbon balance of China is focused by many researchers in recent years [22-25]. The fast development of economy, rapid increase in C emission, large area reforestation and forest conservation, has increased carbon sequestration potential. At the mean while, China has become one of the three high nitrogen deposition regions. Nitrogen deposition status and future development trend has become very important environmental problems [26]. The impaction of nitrogen deposition on the ecosystem should be integrated into biogeochemical models to quantify and analyze.

In this study, we focus on the both spatial and temporal nitrogen deposition in China using the remote sensing data and ground observation data. And we predict the C balance during 21th century under both nitrogen deposition dynamics and different climate scenarios using the Integrated Biosphere Simulator (IBIS). At last， we conclude the nitrogen deposition impact on different vegetation function types under future climate change seniors from IBIS simulation results.

2. Method and Data

2.1. Framework of simulation

The flow of data preprocessing and Model simulation process is shown in the Figure 1.In short to say our study includes three parts. At first, the NO2 Column Density data were converted into surface NO2 concentration, referring the meteorological station observation data. The second, a series of simulations were set up to estimate budget in China, using IBIS model. At last, the effects of nitrogen deposition on the ecosystem carbon budget were concluded, according the model simulation results.

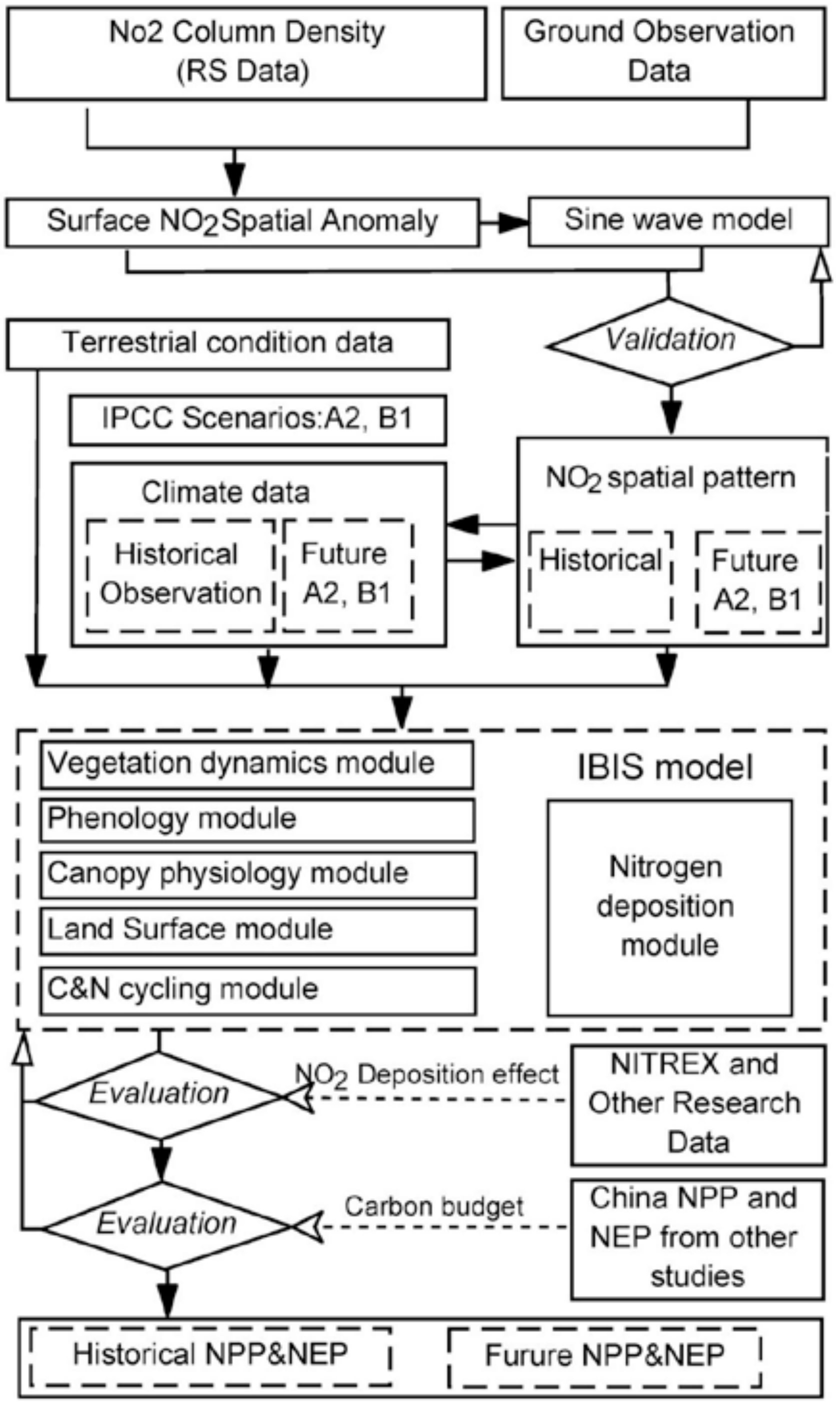

Figure 1 Schematic diagrams of this study. The square blocks represent data. The round-corner blocks represent processes.

2.2. Dry deposition and wet deposition

Nitrogen deposition is composed of two major parts, dry deposition and wet deposition. In our data processing, we have estimated these two parts respectively.

Dry deposition is effected by the dust and aerosol, the count of it can be represented by following function [27-29].

$$F_{dry} = C \times V_d \qquad (1)$$

Where Fdry is represents the dry deposition, C is NO2 concentration near the ground surface and Vd is dry deposition velocity of the NO2. Surface concentration data of NO2 is mentioned in the 2.3 section. And velocity of the NO2 in China is reported by some previous researchers[30]. So we use results and do not simulate ourselves. The dry deposition velocity we refer to is shown in the Table.1.

The wet deposition is another part of the nitrogen deposition. It is closely related with the precipitation[31-32]. The concentration of nitrogen ion in precipitation is also focused by many researchers in China. And they have concluded the relationship between the wet deposition and volume of the precipitation which is described as a linear function[33-34].

$$F_{wet} = A \times P + B \qquad (2)$$

Fwet is the wet deposition, and P is the volume of the precipitation. A and B are two parameters of the linear function.

Much data about the nitrogen wet deposition and volume of precipitation have been proposed. So we distinguish them by different underlying surface types and give each type a linear function which parameters are shown by Table 1.

Table 1 Dry Deposition and Wet Deposition parameters

PFT	Dry Deposition	Wet Deposition	Wet Deposition
	Vd	A	B
Tropical evergreen forest	0.1	0.0145	0.5506
Tropical deciduous forest	0.1	0.0145	0.5506
Temperate evergreen broadleaf forest	0.1	0.0145	0.5506
Temperate evergreen conifer forest	0.09	0.0145	0.5506
Temperate deciduous forest	0.11	0.0145	0.5506
Boreal evergreen forest	0.1	0.0145	0.5506
Boreal deciduous forest	0.11	0.0145	0.5506
Mixed forest	0.1	0.0145	0.5506
Savanna	0.1	0.007	0.3397
Grassland	0.13	0.007	0.3397
Dense shrubland	0.11	0.0183	0.9635
Open shrubland	0.11	0.0183	0.9635
Tundra	0.07	0.0	0.0016
Desert	0.07	0.0	0.0016
Polar desert	0.03	0.0	0.0016

2.3. NO2 ground observation data and remote sensing data

When we use the Function 1 to calculate dry deposition of NO2, the surface concentration of NO2 can get from ground observation. We have ten meteorological stations' observation records which recorded monthly NO2 surface concentration data. This data provide us accurate and continuous data about nitrogen dioxide. But it can only represent the average atmosphere condition near the meteorological stations. So this data can't adapt to this national scale research.

In order to overcome these advantages, we use the remote sensing data to estimate nitrogen dioxide surface concentration. In the atmospheric remote sensing area, the GOME and SCIAMACHY remote sensing data are two important data sources which provide the capability for monitoring global NO2 atmospheric columns. They both use the DOAS method, which means Differential Optical Absorption Spectroscopy, to inverse the column concentration of the nitrogen dioxide[35-36]. The exact mean of column concentration is the average concentration from the ground to the top of the troposphere. It can't be concerned as the surface concentration. So we can't use the GOME and SCIAMACHY remote sensing data directly and it should be translated into the concentration near the ground surface. The comparison between the surface concentration and satellite-brone measurements of nitrogen dioxide has been done by many researchers before. The results addressed the sensitive of the NO2 column concentration to NO2 near the surface [37; 18; 38]. In our study we use a linear transformation which is based on the fact that there is a good linear relationship between the meteorological stations data and the remote sensing data, shown as the Figure 2.

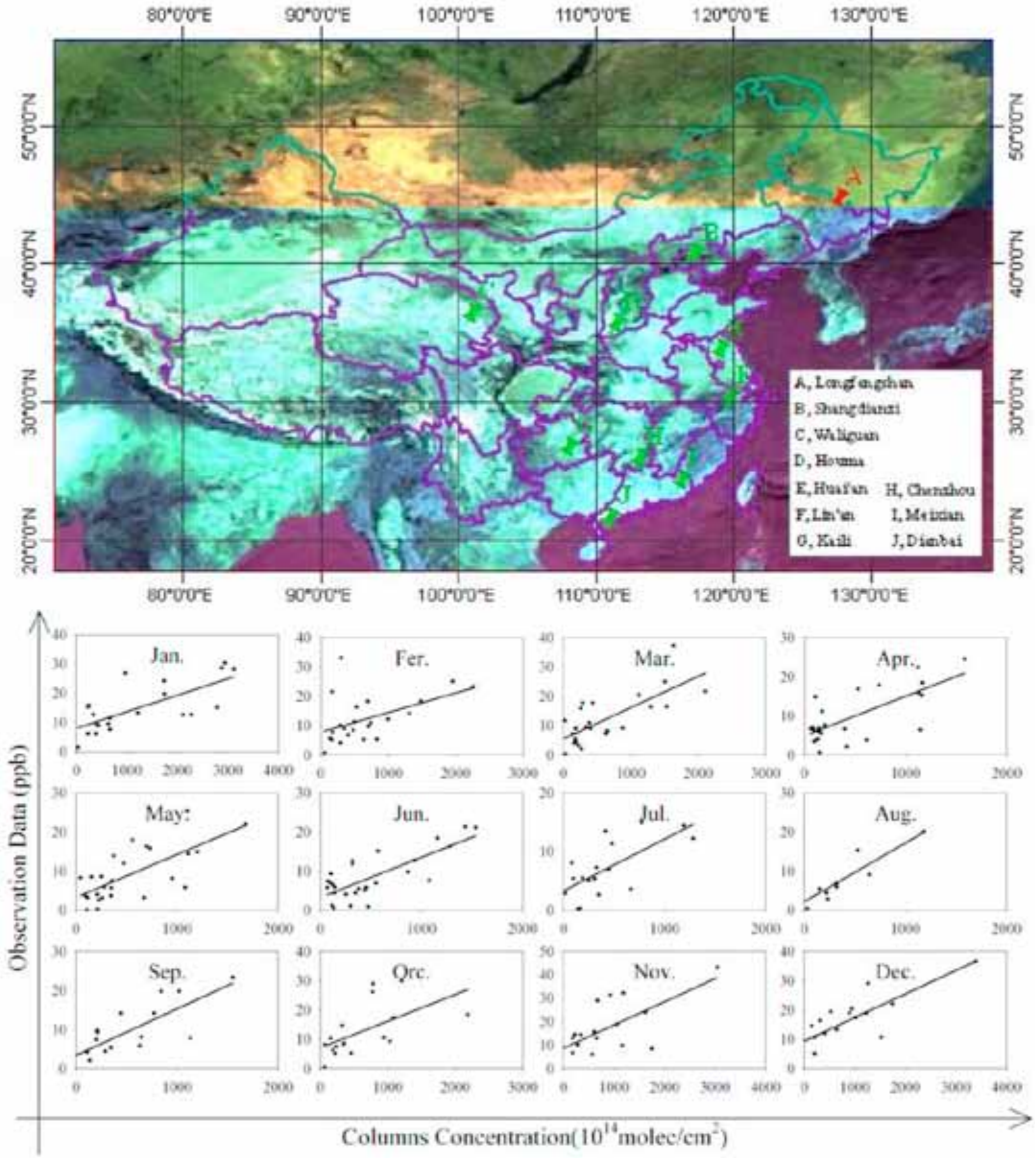

Figure 2 The relationship between the observation data and remote sensing data

In the Figure 2, we show ten meteorological stations' nitrogen dioxide concentration data in the national region during the 2007 to2008. We separate these data by month and compare with the remote sensing data in the same place and time. The result can be concluded that the meteorological stations data and remote sensing data have good linear relationship. So we use the linear functions to perform the transformation between the column concentration and the surface concentration.

Using Function 1 to calculate the nitrogen deposition, we should also know the dry deposition velocity of the nitrogen dioxide. About this part, we use the results in previous researches and do not simulate ourselves [30]. The dry deposition velocity we refer to is shown in the Table.1.

2.4. Build surface N concentration from column data and rebuild historical nitrogen deposition

As we said above, we need built four conditions N deposition data and each condition is consist of two parts, dry deposition and wet deposition.

About dry deposition, we only have the GOME and SCIAMACHY nitrogen dioxide column concentration data from 1998 to 2009.Although we can use the linear transformation, mentioned in the 2.3 section, to get the nitrogen surface concentration from remote sensing column data. However, the time span of data is almost only ten years and it can't meet the needs of the simulation. So we need a method to represent dynamic change of nitrogen concentration. In this study, we found that the sine function, shown as Function 3, can represent the nitrogen dynamic, which is also be found by the other researchers[19; 39].

$$Y_t = A_t + B_t \times X_t + C_t \times sin(2 \times \pi/D_t \times X_t + E_t) \qquad (3)$$

Where Yt is surface nitrogen concentration, Xt is month and A_t,B_t,C_t,D_t,E_t are parameters. At is the y-axis intercept, Bt is the function slope, Ct is the sine function's amplitude, Dt is cycle and Et is phase.

We assume that every raster grid in the region of research consist with the trend of sine function. Therefore we calculate the functions in every raster grid, using the every month nitrogen surface concentration data which derive from remote sensing data. The x variable is time variable in the sine function which means the month in different years. If we set this variable higher or lower, we could get the nitrogen surface concentration in different months of different years. That is to say, we can predict the future and rebuild the history nitrogen surface concentration, shown in the Figure 5.

In order to match the differences scenarios in IBIS model, mentioned in the section 2.5, the other two nitrogen deposition data should be built. We calculated them from normal nitrogen deposition level which is got from the sine function. Then, we set the normal nitrogen deposition level higher 20% or lower 20% in the future. As a result, we had three nitrogen deposition data to drive the model simulation.

2.5. Model scenarios setup

When we simulate the future terrestrial ecosystem carbon budget using the IBIS model, we should setup the model scenarios first. In this study we choose the A2 and B1 scenarios in the IPCC report. These two scenarios are represented two different development modes. P.R China is the faster growing countries in the world and the rapid economic development has brought enormous pressure on the environment. We assume that if we are going on this development mode, the future scenario is A2. And now the Governments of the P.R China are more and more focus on the environmental problem, formulate a serious energy saving politics and promote science and technology into productivity. So if all these are implemented well, the trend of the future climate change will accord the B1 scenario.

From another part, we want to compare the ecosystem responses to different nitrogen deposition levels under different scenarios. So we set four conditions about the nitrogen deposition. The first condition is a fix value of nitrogen deposition that means the nitrogen deposition will not change in the simulation. The second condition is based on the current growth rate of nitrogen deposition. That means we use a method to estimate the current growth rate of nitrogen deposition and make use of this rate to calculate future nitrogen deposition. The third and the forth condition are both concerned about the second condition. The third one is 20% more than the second condition nitrogen deposition and the forth one is 20% less than it.

Different scenarios should match with different nitrogen deposition condition. In A2 scenario, the world is heterogeneous, economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios[40]. So nitrogen deposition will be aggrieved. As a result the third condition of nitrogen deposition is suitable for this scenario. However this match is very thin, we should make it abundant enough to reflect the different dynamic nitrogen depositions impact on the terrestrial ecosystem carbon budget. So we also match the first and the second nitrogen deposition condition to the A2 scenario. B1 is described as a convergent world with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies[40]. So we can imagine that nitrogen dioxide emission will be descended and the nitrogen deposition will be declined too. That is to say, the appropriate nitrogen deposition of B2 scenario is the forth one. As the same reason of the A2 scenario, we append the first and the second nitrogen deposition to the B1 scenario. In summary, we set up six simulation experiments and the details are shown in the Table 2.

Table 2 Conditions of each simulation experiments

NO.	ID	Climate Scenario	Nitrogen Deposition
1	A2_ADD20	A2	20% higher than normal
2	A2_NORMAL	A2	Normal
3	A2_NOC	A2	A constant value, not change
4	B1_EXT20	B1	20% less than normal
5	B1_NORMAL	B1	Normal
6	B1_NOC	B1	A constant value, not change

2.6. Nitrogen deposition as fertilizer and its impacts on carbon sink

Nitrogen deposition may be one of the major reasons of carbon “missing sink”[8]. In the terrestrial ecosystem, the nitrogen limitation is widespread[41]. So that the increasing nitrogen deposition, discharged from industrial and agricultural activity, will take effect on the carbon sequestration. However, these effects are still exist considerable uncertainty. The different results of different models and experiments are shown in the Table 3

Table 3 Nitrogen deposition impacts on carbon sink

Model	Method	Impact(PgC/yr)	Region	Reference
	Element-Matching	0.1	World	[42]
	NDEP Model	03~1.3	World	[8]
	A Simple Budget	0.25	World	[16]
	O-CN	0.2~0.5	World	[43]
	Intel Model	0.024	China	[24]
Experiment	Vegetation Type	Treatment(gNm-2yr-1)	Significant	Reference
	grass land	4	yes	[12]
	loblolly pine	11	yes	[44]
	Norway spruce	10	yes	[45]

2.7. IBIS model details on nitrogen cycling

Integrated Biosphere Simulation (IBIS) was developed by Foley et.al[20]. It is used to estimate the terrestrial ecosystem carbon budget, under changing climate. Nitrogen is an important factor which influences the ecosystem carbon cycle. However, there is no dynamic nitrogen cycling model in the IBIS model. This will increase the uncertainty of carbon simulation. Liu developed a plants-soil nitrogen cycling model and incorporated into the IBIS model[46]. After this modification, the dynamic leaf C:N and soil mineral N was added to control the NPP as long as dynamic leaf C:N determines the foliar and canopy photosynthesis rate and soil mineral N determines the N availability for plant growth and efficiency of biomass construction. In the modification， a series modifiers are designed to control material circulation and energy flow among the plant、ecosystem and soil. In details, the actual maximum carboxylation rate is impacted by the dynamic leaf C:N; the productivity of stabilized biomass is calculated from growth respiration ratio defined, as modified by KP; passive SOM and conserved SOM are incorporated into this version of IBIS and the SOM flux modifier KM and KI are used to depend on carbon decomposition; the ecosystem fluxes among biomass, litter and soil are considered by dynamic C:N ratio at each time step. According these modifies, the IBIS are provided with ability of simulating nitrogen impacting on carbon sequestration.

2.8. Model calibration and evaluation

The accuracy of simulated NO2 surface concentration, using the sine function, should be validated. We checked the adaptation of the sine function, when using it to fit the trend of NO2 surface concentration. The simulated results are compared with ground observation data using 1:1 test chart.

Around world, the validation of IBIS model's parameters and results has been done by many previous researches[47-48] using independent field observation, inventory, and remote sensing data. The validation of IBIS simulated result in China has also been done by some studies. The validation and comparison showed reasonable agreement[49]. Chinese ecological system simulation of carbon budget has also be simulated by other ecosystem models. In this study we were compared our results with some previous studies[50; 23-24; 51-52].

When we evaluate the impaction of nitrogen deposition on ecosystem carbon budget, we set a new variable, response ratio. It is shown as the Function 4.

$$Respo\ ratio = (C_{NDEP\_C} - C_{NDEP\_NOC}) / C_{NDEP\_NOC}$$

The CNDEP_C means the simulation result of NPP or NEP using the variation nitrogen deposition. And the CNDEP_NOC is the simulation result of NPP or NEP using the constant nitrogen deposition. That is to say, CNDEP_NOC is a baseline. Any other simulations results of NPP compare with this baseline under the same climate scenario. In order to found out nitrogen deposition impact on carbon budget.

3. 3. Results

3.1. Model validation

3.1.1. Validation of the sine function

In the temporal pattern, the relationship between the NO2 column concentration and observation surface concentration has been represented in the Figure 3.

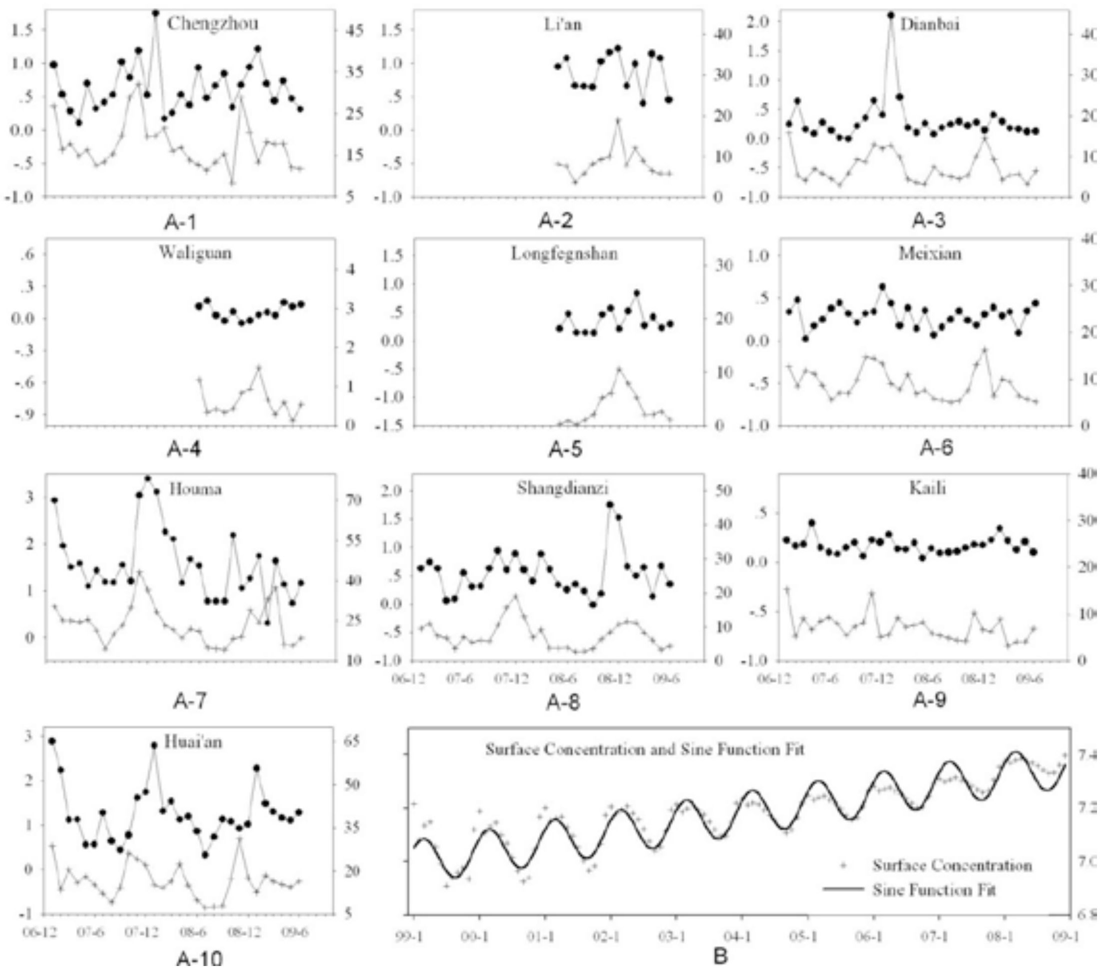

Figure 3 Relationship and Sine Function Fitting

In the Figure 3, the left y axis means NO2 column concentration(1017 molec/cm2) and the right y axis means the surface concentration(ppb). As the Figure 3A shown, the column concentration and surface concentration, in general, have the same change trend and the trend appears regularity which can be fitted by sine function. In the Figure 3B, the average surface concentration around the whole country is fitted by the sine function. We can conclude that sine function can represent the dynamic of surface concentration well.

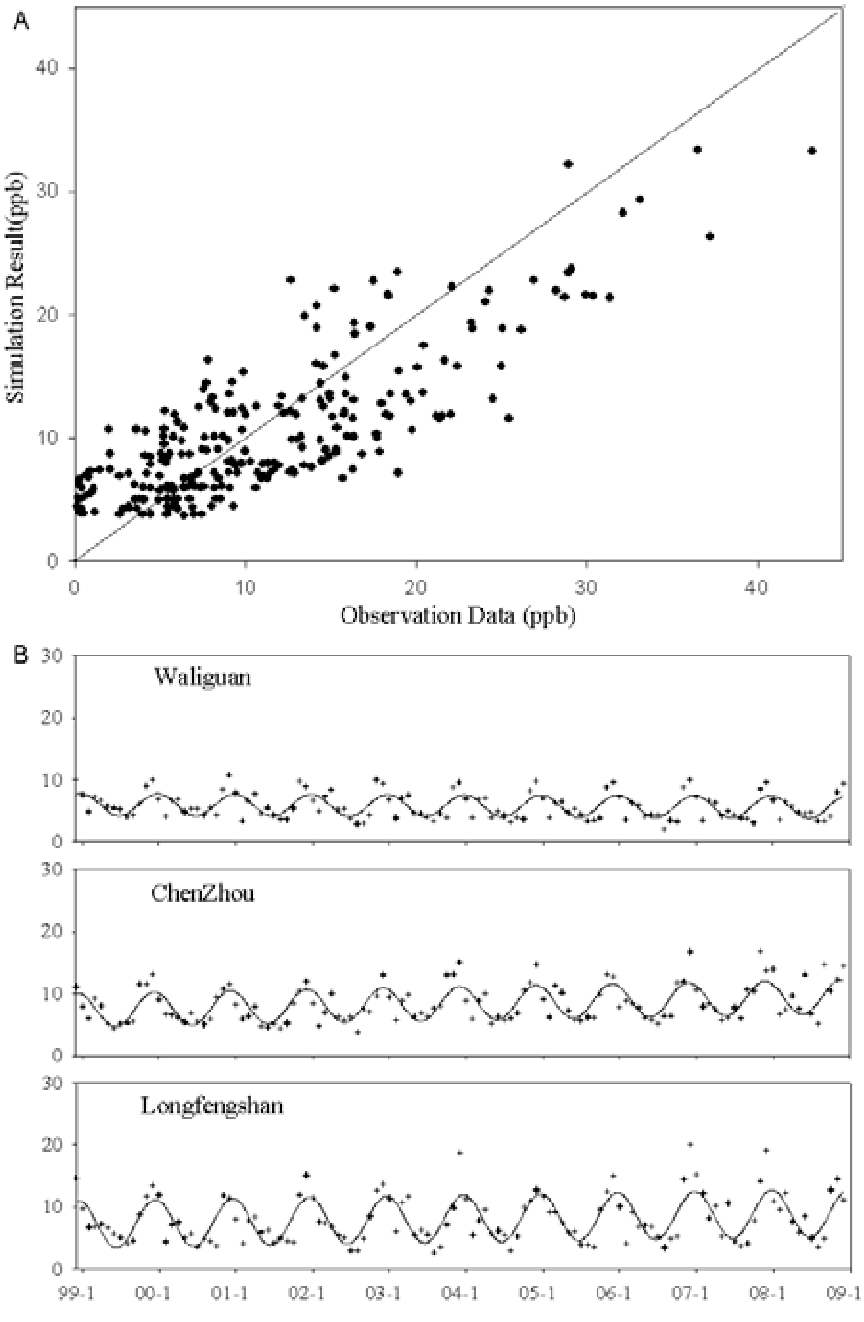

Figure 4 the Validation of the Simulated NO2 Surface Concentration

Figure 4 show the validation results of the NO2 surface concentration simulation. In the Figure 4A, the simulated NO2 surface concentration results are compared with observation data using 1:1 plot style. Most of the scatter points are located in the both side of 1:1 line averagely. The Figure 4B show the sine function simulation results in some grid where the meteorological stations located in. The cross points represent the NO2 surface concentration which is transferred by linear transformation. And the sine curve shows the simulated trend of these points.

Both in the Figure 4A and Figure 4B we can see that the simulation not done well when the NO2 surface concentration is high. As we all know that NO2 surface concentration is sensitive to lots of factors such as atmospheric conditions, nitrogen emission source and so on. It would be sudden rise when these factors changed. Using the sine function, the consistent amplitude cannot fit the sudden rise of the surface NO2 concentration. Therefore, when NO2 surface concentration is higher, the errors will be greater. However, most data is distributed in low value part where the sine function can fit it well. So the simulated results still reflect the regular pattern and tendency of data.

3.1.2. Validation of the IBIS results

There are several previous research interested in the carbon budget in China, shown in the Table 4. They used different methods to simulate the terrestrial ecosystems carbon cycle, such as forest inventory, remote sensing, process-based model and atmospheric inversion. Our simulated results are in the range of previous research. During the 1980-2000, the NPP is 2.59 PgC/yr, which is almost at the top of other researches, as the mean while, the NEP is 66.4 TgC/yr, which is little lower than the previous ones. These results reflect nitrogen deposition impacting on ecosystem. More nitrogen input will promote the carboxylation rate and it also alters the soil carbon decomposition and SOM decomposition. All of processes and more details have been incorporated into IBIS model, which had been embody in our simulated results.

Table 4 Research results of carbon budget in different studies

Category	Period	NPP(PgC/yr)	NEP(TgC/yr)	Reference
Total	1980-2000	—	105± 48.3	[25]
Total	1995-1998	3.09	70	[53]
Total	1981-2000	2.94	100	
Total		2.235	—	[54]
Total	1997	1.95	—	Piao et al,2001
Total	1980-2000	2.59	66.4	This study
Forest	1982-1993	—	58.4± 25.8	
Forest	1990-1999	1.13	189	[24]
Forest	1901-2001	—	32.9± 22.3	[55]
Forest	1980-2000	0.95	91.6	This study

3.2. Spatial and temporal nitrogen deposition changes in China

3.2.1. NO_2 surface concentration simulation

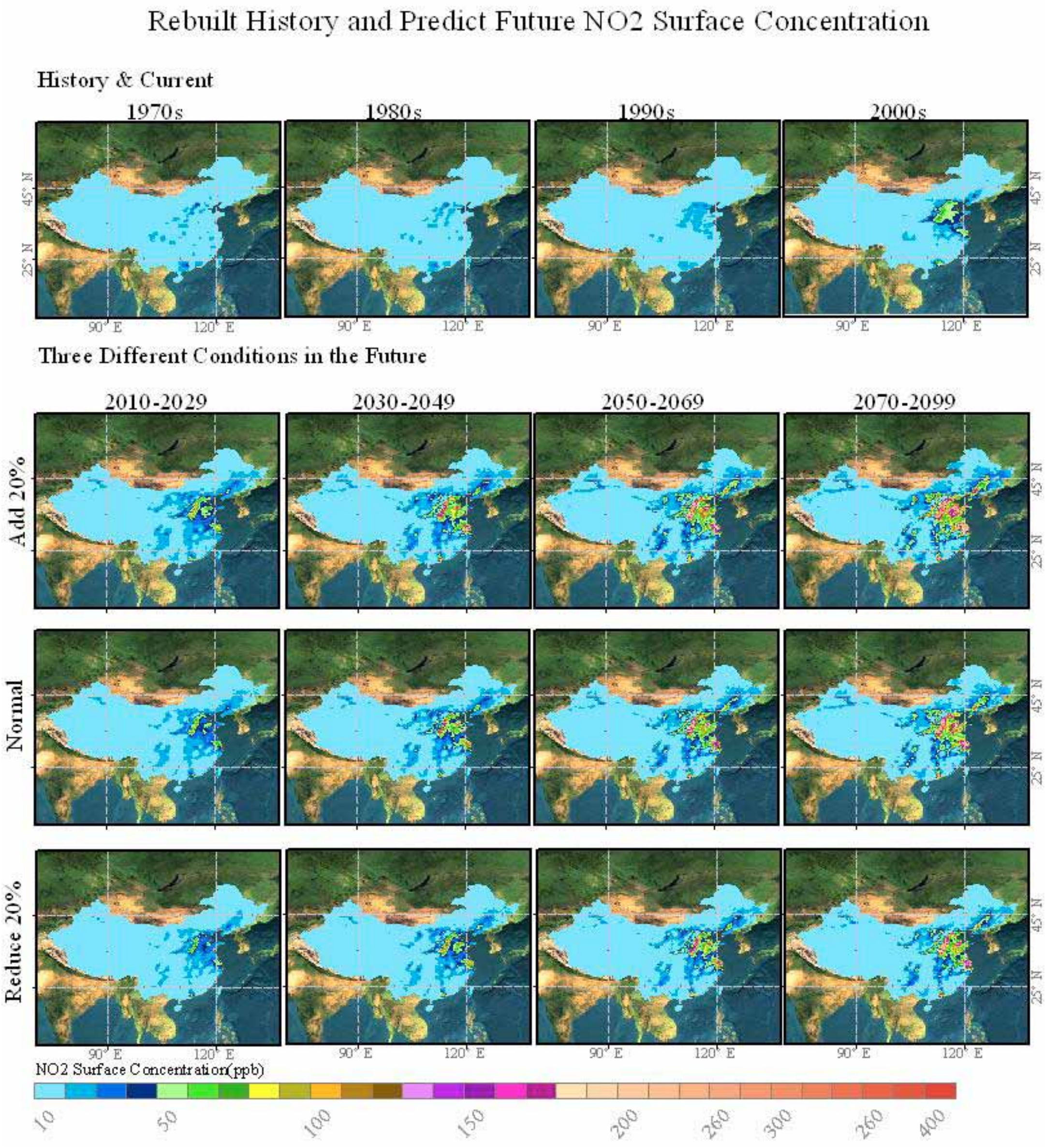

Figure 5. Rebuilt history and predict future NO2 surface concentration in China

The Figure 5 we can see the spatial pattern of NO2 surface concentration in the history and current. And it also shows the spatial pattern of NO2 surface concentration in the future with three different conditions we assumed.

We can conclude that Spatial heterogeneity of the NO2 have relationship with the distribution of industry zone, urban agglomeration and Agricultural area.View from a nationwide, the NO2 surface concentration in the east is higher than the west. The especial high value appeared in the region around the Bohai bay and Yangtze delta area. The result can be concluded that the cities of China are distributed in the East with high density. Along with the rapid development of Chinese eastern cities, fossil fuel emissions and land use changes will intensify. It impacts on nitrogen discharge and make it becomes more and more serious. North China plain is another area with especial high NO2 surface concentration. This area is traditional cultivation areas agriculture where the fertilization of the agricultural ecological system is common. Agricultural fertilizer will increase NO2 surface concentration according nitrification and denitrification [56-57]. Furthermore, the northeast industrial zone, the Sichuan Basin, the pearl river delta is higher than the other parts of China.

3.2.2. Nitrogen deposition in China

The dry deposition and wet deposition have been introduced in the previous text respectively. Combined with future climate change data, we set four nitrogen deposition levels, which have been mentioned in the 2.5 section. The simulated nitrogen deposition results are shown in the Figure 6.

Different period level of nitrogen deposition shows increasing trend. However, the increasing rate is huge different in the spatial. The eastern China changes faster than the western. In the western China, The Qinghai-Tibet Plateau is an area always with lower nitrogen deposition. The nitrogen deposition there is only 0.3 g.m2.a-1, which is almost equal to the nitrogen deposition background value, 0.2~0.5g.m2.a-1[58]. In the eastern China, the changes in The North China Plain and the Yangtze River Delta are more significant than other parts. In large parts of these areas, the nitrogen deposition is less than 0.5g.m-2.a-1 in the 1970s but more than 6g.m-2.a-1 at the end of our simulation. The southeastern China always keeps the high nitrogen deposition level. The increasing rate in this area is no more than The North China Plain and the Yangtze River Delta, except the Pearl River Delta which is another hot spot of nitrogen deposition. At the end of this century, the nitrogen deposition of this hot spot will be more than 6g.m-2.a-1 too. In the northeastern China, the nitrogen deposition in the boreal forests is low but in some urban agglomeration like Shenyang, Dalian, the nitrogen deposition increased fast.

Nitrogen deposition represents some regularity in spatial and temporal. Nitrogen deposition is sensitive to human activities. With the strengthening of human activities, such as fuel combustion, land use and cover change, volatilized from the agricultural fertilization, nitrogen deposition level will be intensified. In northern and western China, the spatial and temporal changes of nitrogen deposition are not evidence which is related to the less human activities and stable natural environment. In eastern coastal areas, trend of nitrogen deposition demonstrates increasing year by year. In the region, the city agglomerations in the Yangtze River Delta, the Pearl River Delta and around the Bohai bay are nitrogen deposition hot spot. These city agglomerations are the center of economy, industry, population. Nitric pollution caused by human activities is the main reason leading the serious nitrogen deposition. In the cultivation areas, such as the North China Plain and Chengdu plain the nitrogen deposition is also high. That may be related with the wide use of nitrogenous fertilizer.

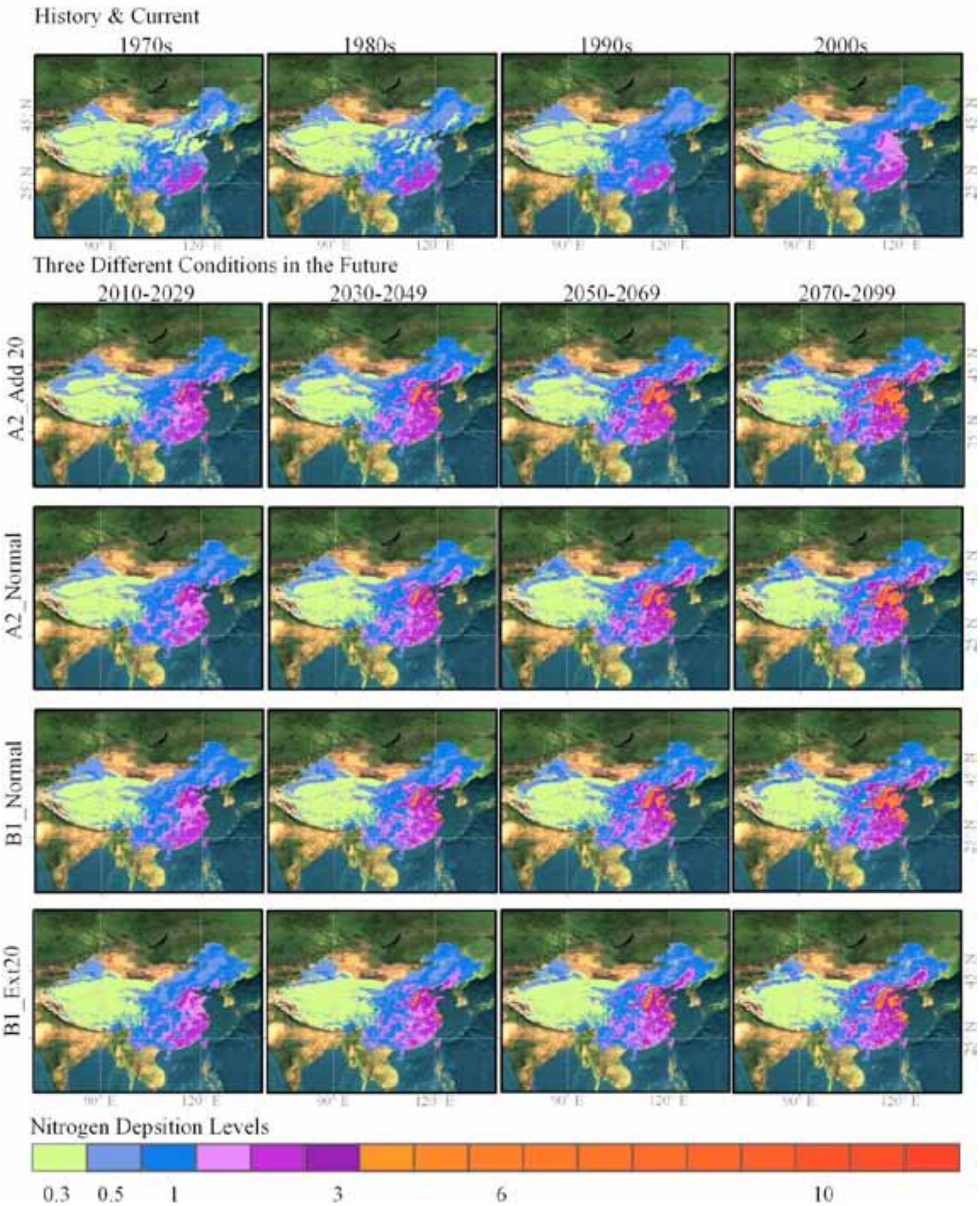

Figure 6 Simulated results of nitrogen deposition in China

3.3. NPP and NEP of the historical period

3.3.1. Temporal variations of NPP and NEP in the history

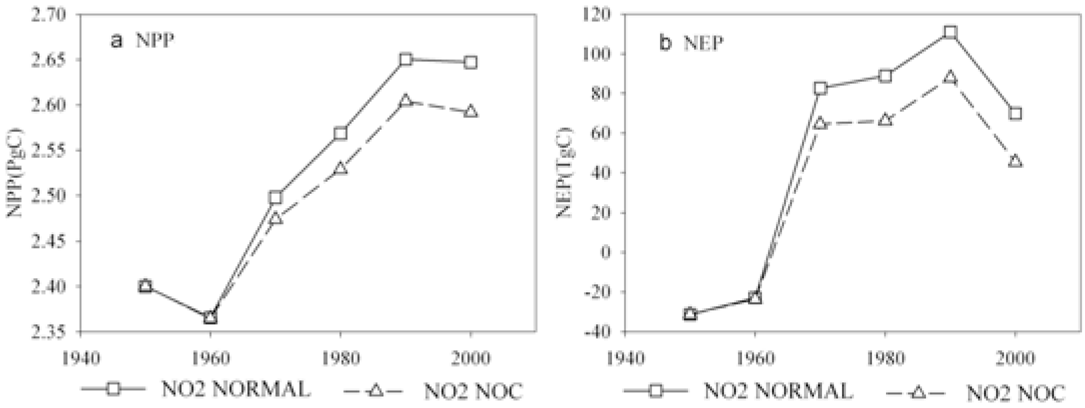

Figure 7 (a)Temporal variations of NPP in the history; (b)Temporal variations of NEP in the history

The temporal variations of NEP and NPP in the history are shown in the Figure 7. The simulated results have been averaged by decades from 1950 to 2009. The result of NPP, using the normal nitrogen deposition data, increased from 2.4 Pg C yr-1 to 2.65Pg C yr-1 in the history. Average increases by 0.04 Pg C yr-1 per decade. Since 1960, NPP has maintained rapid growth. The peak of the increasing appeared in 1990s. Then it declined slightly. The trend of result, using the no change nitrogen deposition data, is similar to the NO2 NORMAL result. On average, it is 0.03 Pg C yr-1 lower than that of the NO2 NORMAL simulation. Such discrepancies shows different nitrogen deposition levels influence on carbon sequestration.

The variation tendency of NEP is similar to NEP, generally. But the growth rate shows some differences. Since 1960, the NEP increased rapidly. But after 1970, growth rate decreased obviously. Then the NEP declined after 1990s. The summit of NEP is 111 Tg C yr-1, which was appeared in 1990s.

3.3.2. Spatial variations of NPP and NEP in the history

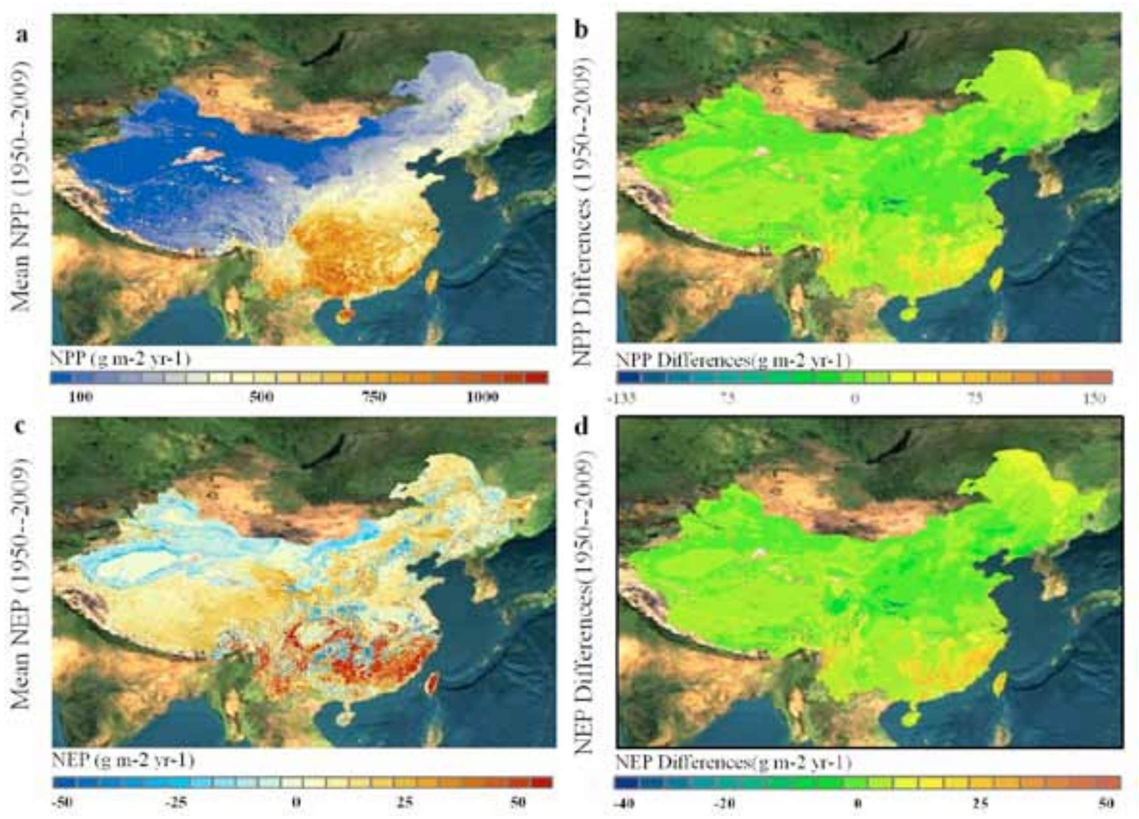

Figure 8 The Spatial Pattern of NPP and NEP in the history and their differences between the 1950 and 2009

The Figure 8.a is shown the mean NPP between 1950 and 2009. The highest NPP is distributed in the south of China where the NPP is more than 750 g m-2 yr-1. In the some parts of the southeast coastal area, the NPP is more than 1000 g m-2 yr-1. Some higher NPP, around 500 g m-2 yr-1, is allocated in the Northeast of China where the boreal forest is widespread. Northwest and the Qinghai-Tibet Plateau is the area with the lower NPP. This distribution result is similar to previous studies [piao,fang]. The Figure 8.b is shown the NPP differences between the Normal and NOC nitrogen deposition level. This Figure indicates the different impactions under different nitrogen deposition levels. The Southeastern China, a serious nitrogen deposition area, is sensitive to nitrogen deposition increasing. The NPP in this area increased from 15 g m-2 yr-1 to 50 g m-2 yr-1. However the central and north of China, where the nitrogen deposition is the most serious, is not sensitive to the change of nitrogen deposition.

The mean NEP in the history is shown in the Figure 8.c. The south of China is region with higher NEP. The carbon sequestrate in this region is form 25 g m-2 yr-1 to 50 g m-2 yr-1. This result is consistent with some recent findings. The positive response to nitrogen deposition increasing is in the south east of China. The NEP was increased about 25 g m-2 yr-1 during the history period.

3.4. NPP and NEP under IPCC A2 and B1 scenarios in future

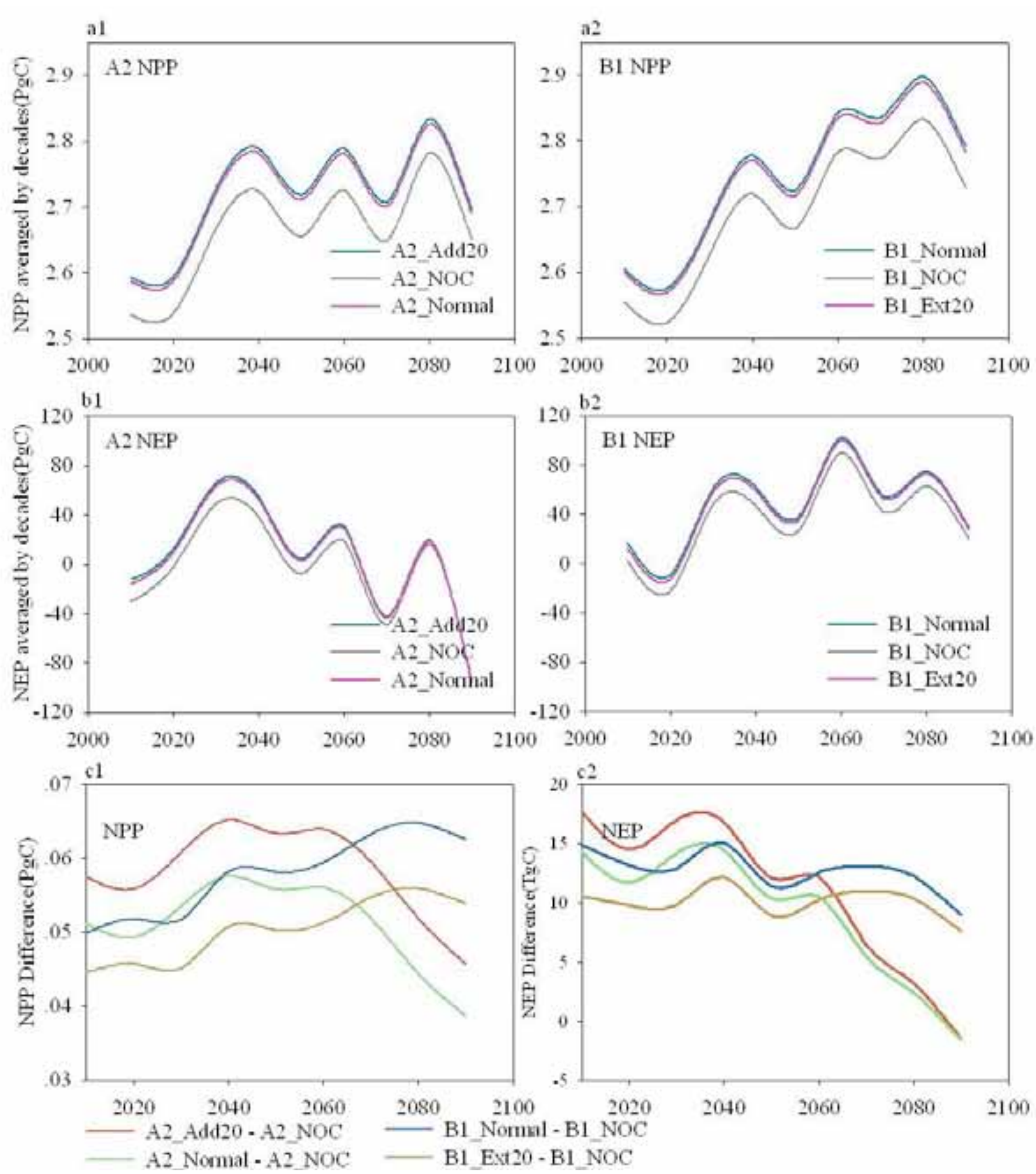

Figure 9 (a)the Variations of NPP under A2 and B1 Scenarios;(b) the Variations of NPP under A2 and B1 Scenarios;(c)the difference between the dynamic nitrogen deposition and fixed nitrogen deposition

As the Figure 9 shown, the NPP in China will be increased under different scenarios. The Simulated NPP under B1 scenario will increase more than the NPP under A2 scenario. From 2020 to 2040, the fastest increasing period of NPP in the future, the NPP will increase about 0.01 Pg C per year. The summit of NPP will receive in the year around 2080. The impactions of nitrogen deposition on NPP are different. The sensitive to nitrogen deposition under A2 scenario will decline after 2060s when the NPP under B1 scenario will increase continuously. The NEP in China will increase between 2010 and 2040. After 2040, the NEP under A2 scenarios will decline, but NEP under B1 scenario will vibrate near 50 Tg C. According to simulated NEP under A2 scenario, China will be become a carbon source after 1950s. Comparing with NPP, NEP is more sensitive to nitrogen deposition. However, when the nitrogen deposition becomes serious, sensitivity of NEP will be weaken. The weaken magnitude of NEP under A2 scenario is more sharpen than the NEP under B1 scenario.

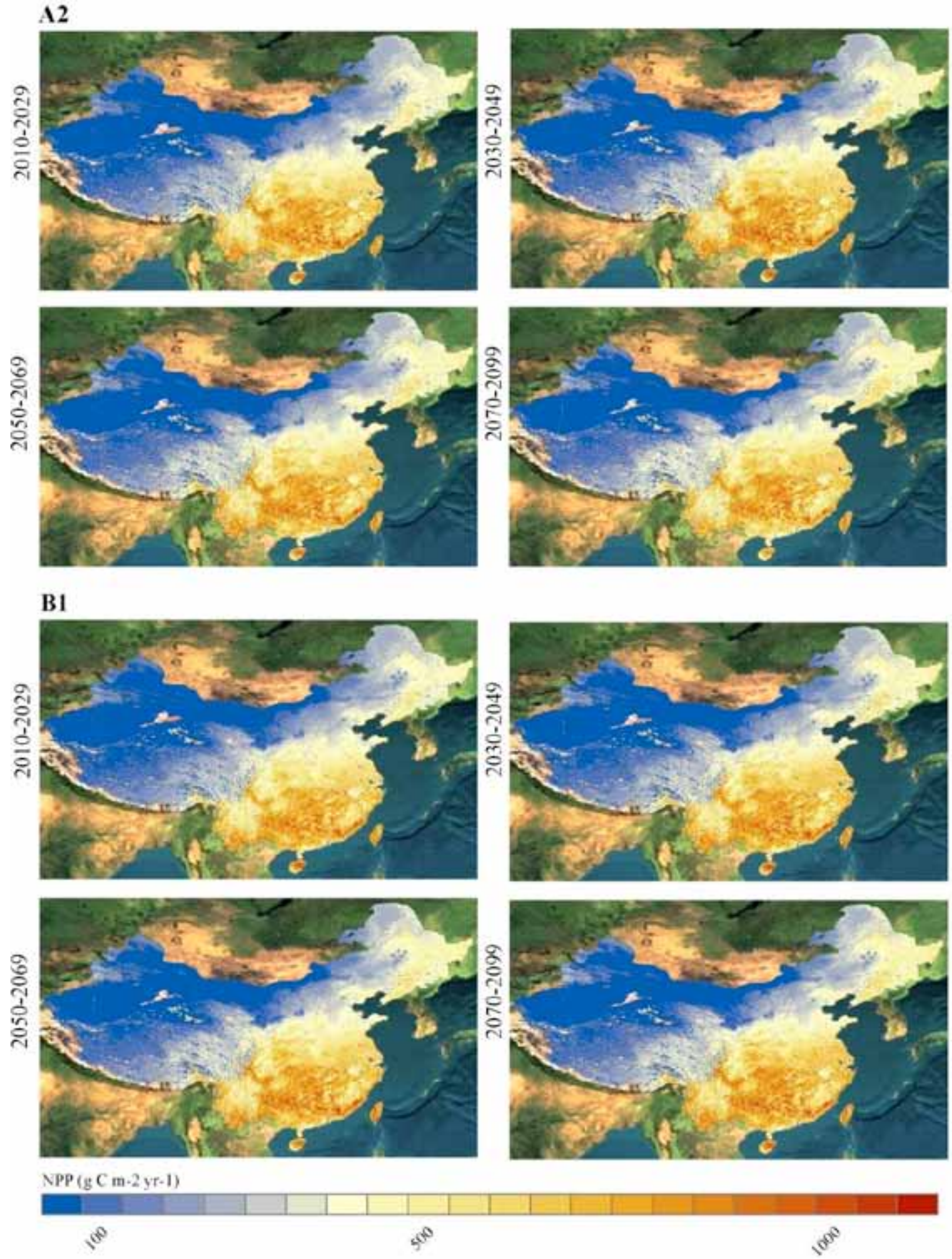

Figure 10 Spatial pattern of NEP in the Future by decades

The mean NPP by decades under A2 and B1 scenarios are shown in the Figure 10. In the future, the south of china will be the main area of carbon assimilation and the west of China is weak in carbon assimilation. Under different climate scenarios, NPP changes occurred mainly in southern China. In this area, NPP will decline after 2050 under A2 scenarios, but until the end of the century, NPP has always been to maintain growth under B1 scenarios. The NPP variation in other parts of China is not very clear.

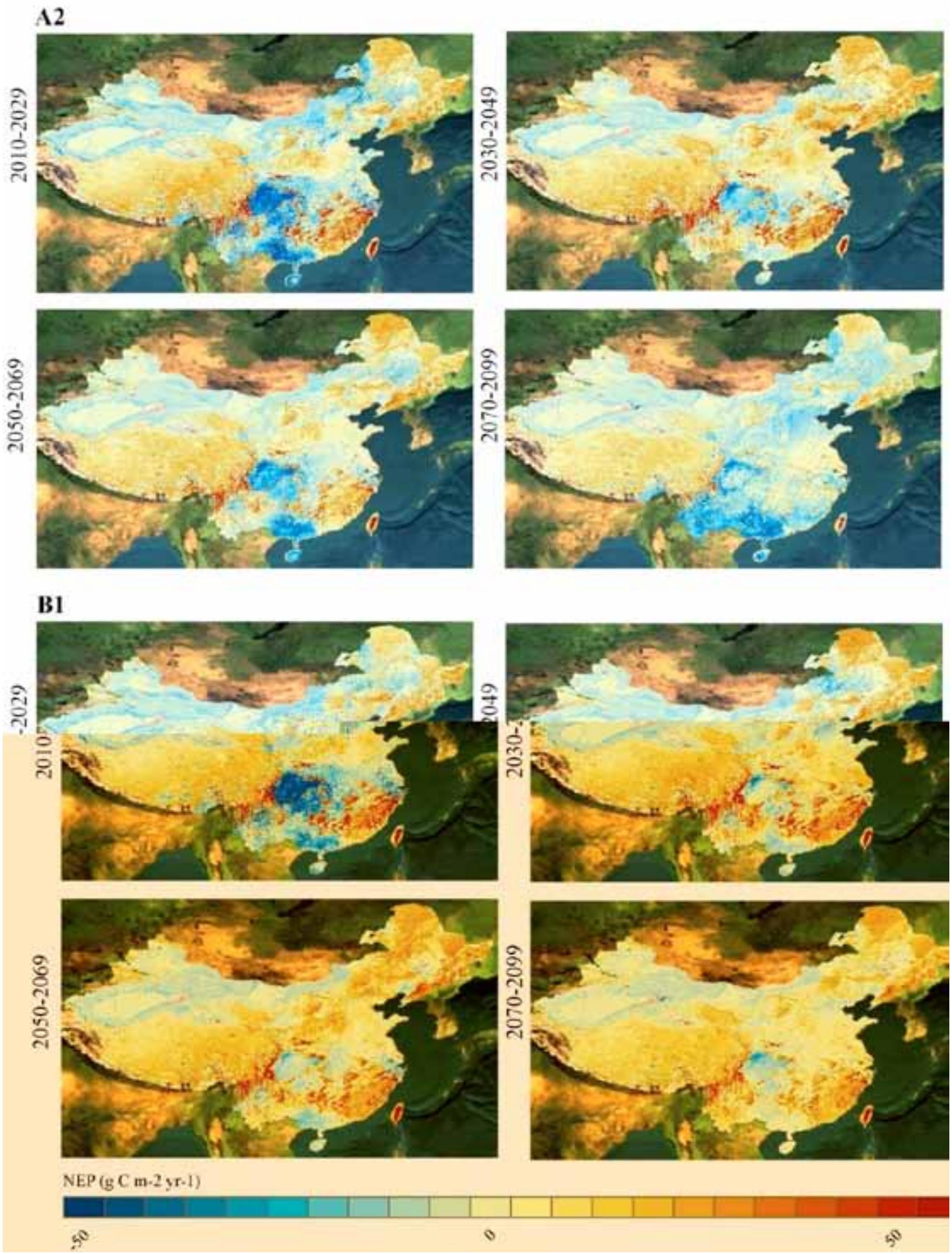

Figure 11 Spatial pattern of NEP in the Future by decades

The NEP will take a large change in the future during 2010 to 2099. Under A2 scenario, south of China will become carbon source from carbon sink. At the same time, NEP in the north of China will decline serious. In some northern area, the NEP will be negative. At the end of our simulation, the main carbon sink will be located in Tibet, Daxinganling, Changbai Mountain and China will become a carbon source. The situation under B1 scenario is very different. The NEP will increase until the middle of this century. Then it will be decline a little. At the end of simulation, the large area of China is a carbon sink except Xinjiang and Sichuan basin.

3.5. Impacts of nitrogen deposition increase on C sequestration of different vegetation types.

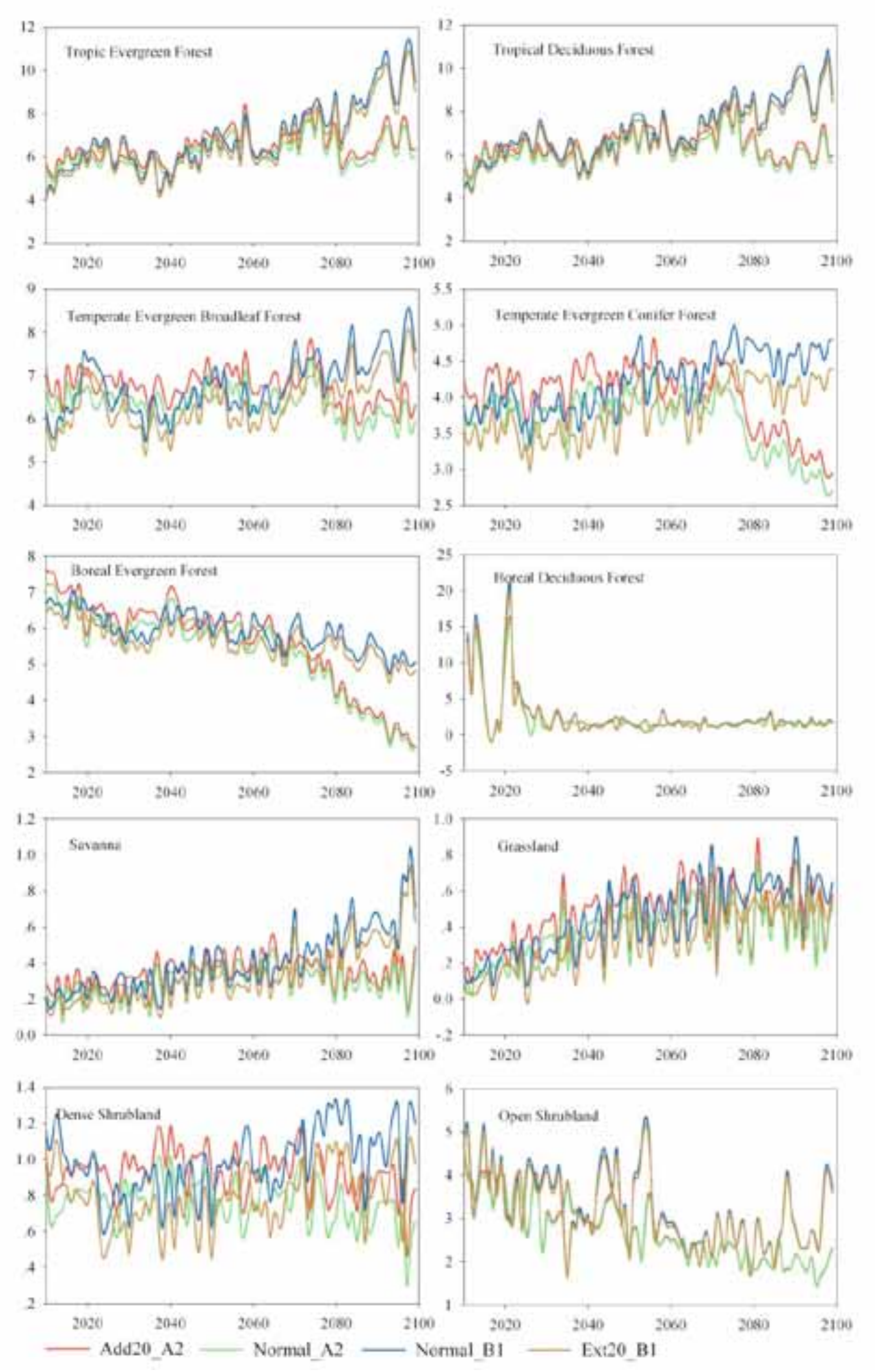

Figure 12 NPP Response Ratio of Different vegetation types

The Figure 12 uses the response ratio to represent the impaction of different nitrogen deposition. The differences of NPP outputs between nitrogen deposition change and nitrogen deposition not change simulations were calculated to figure out the NPP sensitivity to the increasing nitrogen deposition respectively. Different vegetation types show the different changes when the nitrogen deposition is grown up. Some vegetation types, like savanna and grassland, have positive response, straightly. Some vegetation types, like boreal evergreen forest, open shrubland, have negative response. And the responses of other vegetation types show increasing at first; and then they become stable; at last some ones show a downward trend. The increasing time and amplitude and the beginning point to turn down of different vegetations' response ratio are different. It is related to property of the vegetation types and nitrogen deposition.

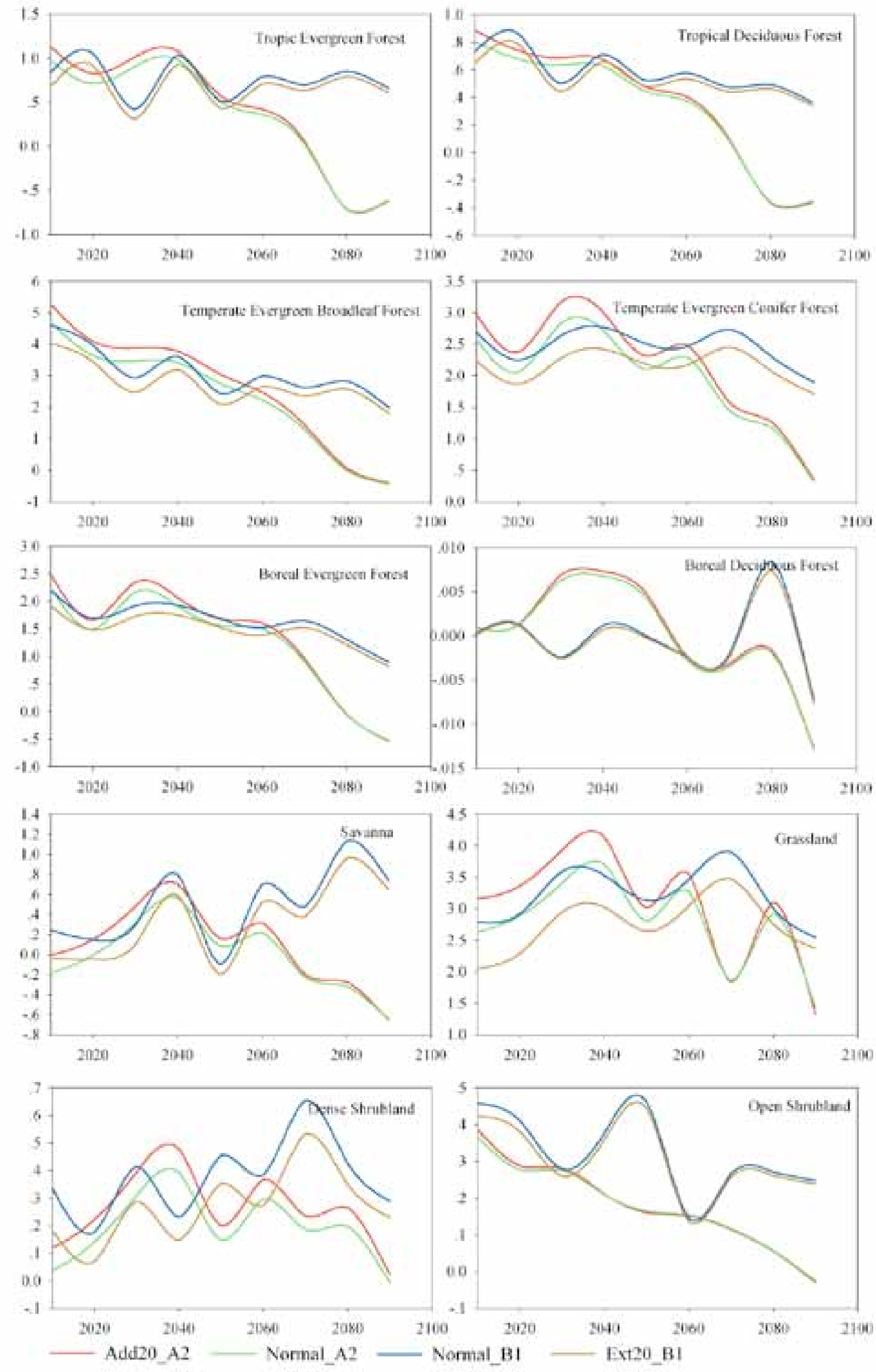

Figure 13 NEP Response Ratio of Different Vegetation Types by decades

The response ratio of NEP per year has the large amplitude which affects the demonstration of NEP sensitive to nitrogen deposition. So we average the response ratio by decades and the results are shown in the Figure 13. Under A2 scenario, NEP response ratio will be decline in the future. The response ratios of forest vegetation types will decline more sharpen than the other vegetation types. Under B1 scenario, the response ratios of forest vegetation types will be maintained well and they only will decline slightly during the simulations. Some response ratios of herbaceous vegetation types will be increased such as savanna, grassland and dense shrubland. In summary, B1 scenario is more sensitive to nitrogen deposition.

4. Discussion

4.1. Nitrogen deposition influence carbon sequestration

Although there are a lot of assumptions and inadequate in nitrogen deposition data producing, it is a still important way to study nitrogen deposition influence on carbon sequestrate by integrated nitrogen deposition data into IBIS model. In the convention of nitrogen dioxide column density to surface concentration, we only have ten meteorological stations ambition observation data which can not represent the station of whole country well. If we could get more sites of data and the data with longer span, we can make the regression more accurate. There still some shortage in sine function which can not represent higher value well. It can be contributing to that the nitrogen dioxide mutation in time. It could be caused by the weather and some air pollution incident.

The sensibility of ecosystem to nitrogen deposition is changed all the time. The increasing of nitrogen deposition not only impacts on photosynthesis but also takes effect on soil respiration. Coupling with the carbon and water cycling, the sensibility of ecosystem to nitrogen deposition increasing shows some uncertainty under different future climate scenarios.

4.2. The response of carbon sequestrate to nitrogen deposition and climate change

Different vegetation types have different response to nitrogen deposition. The response of forest NPP to nitrogen deposition is more sensitive than shrubland and grassland's NPP. Around all kinds of forest types, tropical forest, including tropical evergreen forest and tropical deciduous forest, will be taken high effects by nitrogen deposition especially under B1 scenarios. The lower impactions of nitrogen deposition on shrubland and grassland can due to that the nitrogen is not the only restricted factor on NPP. Temperature, water or other factors may also restrict on the NPP significantly in these vegetation types.

Most vegetation types' NEP response to nitrogen deposition will decline in the future under A2 and B1 scenarios. Temper ever green broadleaf forest will be the most sensitive to the nitrogen deposition. But the sensibility will be decline sharpen in the future. This could be result of the soil respiration is more sensitive to nitrogen deposition in this type of forest.

From the sensitive curve of NPP and NEP to nitrogen deposition in Figure 12 and Figure 13, we can find that nitrogen saturation assumption is shown. When the ecosystem needs nutrition, the ecosystem will be more sensitive to nitrogen deposition. When the ecosystem is nitrogen saturation, the more nitrogen deposition will not increase sensitive any more. As long as the sustained nitrogen deposition, the nitrogen will take negative effects on ecosystem. Our research indicate the nitrogen requirements of different vegetation types under future climate change.

4.3. Increase accuracy of C budget estimation and future plan

Many methods are used to the researches on the carbon budget. The approach of model and remote sensing is one of them. All of these methods own their characteristics, respectively. According the controlled experiment, we can research many uncertain issues about ecosystem. But the controlled experiment is very expensive and only represents the area around the site. Using the ecosystem model can avoid the disadvantage of the controlled experiment and suit for the large scale carbon estimate. With the continuous development of ecological models, more new discoveries and reasonable assumptions are integrated into the model which gets more continuous improvement. As a result of development of remote sensing, ecosystem model get more effective and accurate data source. Combined the IBIS model with the nitrogen deposition, gotten from the remote sensing data, is another important work on the carbon cycling research.

There are still lots of argument on the affection of nitrogen deposition. The assumption, used in the Model, needs the wild experiment to confirm. Nitrogen deposition is one of the aspects which influence the carbon budget. The water, temperate, the enrichment of atmospheric CO_2 and many other aspects take their effect on the ecosystem. With the changing of the precipitation and temperature and the elevating of the CO_2, CH_4, the simulation of the ecosystem carbon budget become very complex. Therefore, we should research on the model deeply and establish a coupled model with main influence factors in order to make the simulation more accurate.

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